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## INVESTIGATION OF FRICTION AND WEAR OF STEELS, A HARD ALLOY, AND POLYMER MATERIALS AT LOW TEMPERATURES

by

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# EDITED TRANSLATION

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INVESTIGATION OF FRICTION AND WEAR OF STEELS, A HARD ALLOY, AND POLYMER MATERIALS AT LOW TEMPERATURES

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The construction of friction units for low-temperature machines presents the designer with certain difficulties connected both with the structural design of the friction units and with the selection of materials for the friction surfaces. The operating conditions of friction pairs in low-temperature machines are distinguished by a significant characteristic. For example, in contemporary compressed-gas motors the temperature in the zone of friction between the ring and cylinder can reach 11°K, while the parts of the plunger pairs in pumps for liquefied gases operate at temperatures on the order of 70°K [1]. In these cases the conditions of friction and wear are radically different from those which obtain in ordinary machines. Owing to the absence of lubrication and the very low temperatures, the effectiveness of friction units very frequently is completely inadequate. Thus, the service life of plunger pairs in liquid oxygen and nitrogen pumps reaches in all 1000 hours.

At the present time polymer materials, which operate significantly better at small specific pressures than steel and cast iron, are applied in friction pairs of compressed-gas motors. However, in those cases when friction pairs operate at high pressures the high-strength steels cannot always be replaced with polymers. Therefore the question of investigating friction and wear of various materials at low

temperatures is of considerable interest.

However, the literature contains only a small number of works dedicated to this problem [2, 3]. The published works present only comparative data on the wear resistance of individual steels at low temperatures; the influence of certain important factors, in particular specific pressure, on wear has not been studied, although this question is of great interest both from the practical point of view and for the theory of friction and wear [4, 5].

This article presents the results of friction and wear tests of the hardened steels ShKh15, U10, and 38KhMYuA, the hard alloy VK8, and of polymer materials under different loads in a medium of liquid nitrogen; also included are results of measurements of the hardness of tested specimens under both normal and low temperatures.

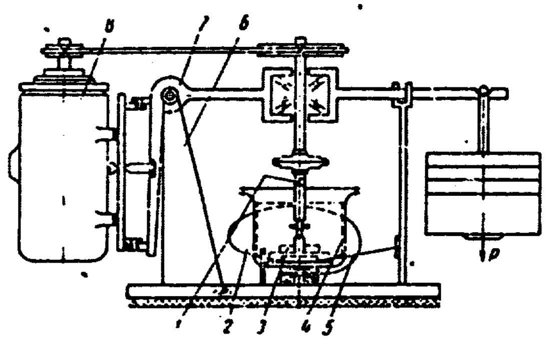

Fig. 1. Diagram of friction machine. 1 – shaft; 2 – cryochamber; 3 – clamp; 4 – screen; 5 – elastic element; 6 – base; 7 – lever loading device; 8 – electric motor.

Investigation of the specimens was conducted on an installation which was specially designed and fabricated for this purpose (Fig. 1); it was constructed on the principle of base-type friction of specimens. The machine consists of the following basic parts: a vertical shaft, a cryochamber with powder-vacuum insulation, a lever loading device, an electric motor, a screen, and a base.

For the actual conduct of tests the clamp with specimens is fastened to the bottom end of the shaft, while the other specimen is set immovably on the floor of the cryochamber. Three specimens, 3 mm in diameter, of different steels were set on the upper clamp; under the action of the applied load their faces were forced against the lower specimen of the disk. Motion is transmitted to the vertical shaft from the electric motor through a belt drive. The cryochamber, which was installed on a radial – ball-and-socket bearing, was connected with the elastic element; the deformation of the latter determined the friction force.

The friction machine thus designed made it possible to carry out tests of various materials for wear and to determine their coefficients of friction in liquid and gaseous nitrogen and oxygen media. A screen was installed in the cryochamber for the tests in the gaseous medium. In this case the cooling fluid circulates only in the space between the wall of the cryochamber and the screen and does not reach the specimen.

The tests were conducted at specific pressures of 50, 80, and 100 kgf/cm$^2$ and shaft rotation speed of 280 r/m, which corresponds to a slip speed of 1.25 m/s. The test time comprised six hours (for one pair of specimens). Before testing the steel specimens were subjected to optimum heat treatment: hardening at 850-880°C and tempering at 170°C to the hardness HRC 58-60, and then were polished to a surface finish of ∇9-∇10. During the tests only the material of the upper specimens was changed. The material of the lower specimen was nitrided steel 38KhMYuA with HRC of 60-62 and a surface finish of ∇9-∇10. The magnitude of wear was measured by means of a micron indicator, on the instrument microscope BMI, and on analytical balances.

Before the wear tests a check was made of the hardness of the tested materials under both normal temperatures and the reduced temperature in the liquid nitrogen medium. The TKP-1 instrument (Fig. 2) was used for the hardness measurements. An adaptation was made in the TKP-1 for these tests: a cryochamber, open at the top and with powder insulation, was installed on the shaft, and a reducer, which was used to set the cryochamber in the setting position of the lifting

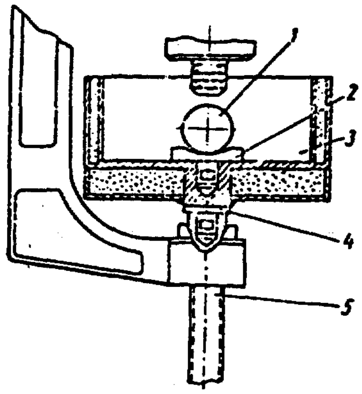


Fig. 2. Diagram of measuring the hardness of specimens on the TKP-1 instrument. 1 — specimen; 2 — stand; 3 — cryochamber; 4 — adapter; 5 — shaft.

screw, was fastened to the bottom of the cryochamber with screws. The bottom of the cryochamber was provided with a blind opening with a vertical groove on the wall to permit the escape of air; the platform for the specimens was placed in this blind opening.

For the test the specimens were placed on the table, nitrogen was poured into the cryochamber, and after the specimen had cooled the hardness measurements were carried out. Table 1 shows the results of hardness measurements for a number of steels.

Table 1

| Steel | Hardness of steels at various temperatures | |
|---|---|---|
| | Normal temperature | At 77°K |
| Kh17N2 | 36,5 | 40,8 |
| 12KhNZA | 36,3 | 44,2 |
| ShKh15 | 60,0 | 61,5 |
| U10 | 58,0 | 62,5 |
| 38KhMYuA | 60,0 | 60,0 |
| ON9A | 32,1 | 36,2 |

Table 2

| Material | $h_{max}$ in μm | $r_{av}$ in μm |
|---|---|---|
| Steel: | | |
| ShKh15 | 1,22 | 34 |
| 38KhMYuA | 1,21 | 36 |
| U10 | 1,20 | 40 |
| Alloy VK8 | 0,8 | 42 |

Another matter of considerable interest is the microgeometry of the surface of a steel subjected to wear in a medium of liquid nitrogen. To determine surface finish characteristics we took profilograms from the friction surface on the "Kalibr mod. 202" profilograph. Table 2 shows the data obtained for the maximum height of microirregularities, $h_{max}$, and the average radius of microirregularities, $r_{av}$.

Table 3 shows the results of wear-resistance tests of the steels ShKh15, U10, and 38KhMYuA and the hard alloy VK8 in a medium of liquid nitrogen during friction over steel 38KhMYuA (the test time was six hours).

Table 3

| Specimen material | Specific pressure kgf/cm$^2$ | Wear in mm | Friction coefficient |
|---|---|---|---|
| Steel: ShKh15 (HRC 58-60) | 50<br>80<br>100 | 0,11<br>0,145<br>0,185 | 0,803<br>0,885<br>0,750 |
| U10 (HRC 56-58) | 50<br>80<br>100 | 0,094<br>[illegible]<br>0,170 | 0,708<br>[illegible]<br>0,777 |
| 383KhMYuA [sic] (HRC 58-60) | 50<br>80<br>100 | 0,015<br>0,037<br>0,121 | 0,910<br>0,885<br>0,750 |
| Alloy VK8 | 50<br>80<br>100 | 0,001<br>0,002<br>0,003 | 0,06<br>0,05<br>0,05 |

We also studied friction and wear of certain antifriction materials containing polyfluoroethylene resins in a medium of liquid nitrogen at a slip speed of 1.25 m/s and under various specific pressures. Polyfluoroethylene materials reinforced with various materials and metallopolyfluoroethylene on Klimovskiy Plant strip were tested (the strip was made by applying a porous bronze coating 0.4 mm thick, saturated with filled polyfluoroethylene resin, on a steel tape 1 mm thick). In the course of the investigations we tested the following materials, based on Teflon: 1) Teflon (without filler); 2) Teflon with 20% boron nitride (material from Dnepropetrovsk Chemical Engineering Institute – DKhTI); 3) FN-3 (material from NIIPM); 4) composition 8 (material from NIIkhimmash); 5) Teflon with 30% coke (DKhTI material); 6) FN-202 (NIIPM material); 7) Teflon with 17% graphite (DKhTI material); 8) FG-30A (material from the Institute of the Chemistry of High-Molecular Compounds, Ukrainian Academy of Sciences), and 9) metallized plastic on strip (material from the Klimovskiy Plant).

Table 4

| No. of material | Axial load in kgf | Friction force in kgf | Specific pressure, kgf/cm$^2$ | Friction coeffi- cient | Average wear in mm/hr |
|---|---|---|---|---|---|
| 1 | | | | | 0,028/0,030 |
| 2 | | | | | 0,0186/0,018 |
| 3 | | | | | 0,013/0,016 |
| 4 | 5/5 | 0,51/0,51 | 5,9/5,9 | 0,10/0,10 | 0,016/0,016 |
| 5 | | | | | 0,016/0,015 |
| 6 | | | | | 0,015/0,016 |
| 7 | | | | | 0,0163/0,016 |
| 8 | | | | | 0,016/0,016 |
| 9 | | 0,40/0,41 | | 0,08/0,09 | 0,002/0,002 |
| 1 | | | | | 0,032/0,035 |
| 2 | | | | | 0,022/0,023 |
| 3 | | | | | 0,018/0,020 |
| 4 | 7,5/7,5 | 0,72/0,70–0,75 | 9,0/9,0 | 0,096/0,096 | 0,021/0,022 |
| 5 | | | | | 0,0213/0,023 |
| 6 | | | | | 0,020/0,080 |
| 7 | | | | | 0,021/0,022 |
| 8 | | | | | 0,020/0,022 |
| 9 | | 0,53/0,56 | | 0,070/0,071 | 0,003/0,003 |
| 1 | | | | | 0,040/0,013 |
| 2 | | | | | 0,0273/0,029 |
| 3 | | | | | 0,022/0,025 |
| 4 | 9,6/9,6 | 0,95/0,95–1,0 | 11,90/11,59 | 0,1/0,1 | 0,025/0,026 |
| 5 | | | | | 0,026/0,027 |
| 6 | | | | | 0,024/0,025 |
| 7 | | | | | 0,0250/0,260 |
| 8 | | | | | 0,0260/0,0260 |
| 9 | | 0,58/0,60 | | 0,060/0,062 | 0,005/0,005 |

Remark. The numerator showed the value or the materials during friction over steel ShKh15 while the denominator gives values for the hard alloy VK8.

Abrasion of specimens was conducted under friction over steel ShKh-15 and over the hard alloy VK8 with a surface finish up to Class 12. During the tests we determined the coefficient of friction and the wear of the rubbing pairs; the test time was one hour and the area of friction was 0.84 $cm^2$. Table 4 shows the obtained test results.

Results of the investigations which we conducted concerning the steels and the hard alloy make it possible to conclude that in the general case the dependence of wear of steels on specific pressure in a liquid nitrogen medium carries a nonlinear character. Of the steels tested, the most wear-resistant turned out to be the friction pair of steel 38KhMYuA over steel 38KhMYuA. The wear resistance of the hard alloy VK8 significantly exceeds that of all the steels; its coefficient of friction over steel 38KhMYuA is also significantly less than that of the steel surfaces. Thus, the results of studies of wear resistance of steels in application as wear-resistant materials or friction pairs operating in conditions of extreme cold provide a basis for recommending the hard alloy VK8.

The tests of polyfluoroethylene materials with reinforcing fillers (Nos. 2-9, Table 4) in a liquid nitrogen medium showed that they have approximately identical wear resistance. The difference in wear resistance of materials with fillers comprises 10-30%. The coefficients of friction of the various materials differ insignificantly, by no more than 0.1. Thus, owing to the small difference in wear resistance and friction coefficient of the different filled polyfluoroethylene resin materials, any of them can be applied for operation in a liquid nitrogen medium. Besides this, the insignificant difference in the wear resistance of the pure and the reinforced Teflon means that in a number of cases it is possible to apply it for operation in liquid nitrogen. The reason for the small difference in antifriction properties of the polyfluoroethylene materials in a liquid nitrogen medium apparently lies in the lubricating action of the liquid nitrogen. In addition, an essential role is evidently played in this case by the change in physicomechanical properties of the materials at low temperatures.

These investigations showed that wear resistance of the metalloplastic material on strip exceeds that of all reinforced filled polyfluoroethylene materials tested by about ten times. Therefore this material is preferable in applications in a liquid nitrogen medium. However, the application of metalloplastic on strip is possible only in those cases when the design of the friction unit permits.

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13. ABSTRACT

This article gives the results of friction and wear tests of hardened steels ShKh15, U10, 38KhMYuA, the hard alloy VK8, and polymer materials under different loads in a liquid nitrogen medium and the results of measurements of the hardness of tested specimens at both normal and low temperatures. The testing device shown in a figure was designed particularly for this purpose. In making the tests the clip with the specimens was fastened to the lower end of the shaft and another specimen was mounted immovably on the bottom of the cryochamber. Three specimens of the different steels 3 mm in diameter were installed in the top clip and under the application of a load had their faces pressed against the lower specimen of the disk. A belt drive transfers torque from the electric motor to vertical shaft. The cryochamber is mounted on a spherical radially seating bearing and connected with the elastic element by whose deformation the friction force was determined. The TKP-1 device for measuring hardness is shown in a figure. The steel and alloy tests showed that the dependence of wear on specific pressure in a liquid nitrogen medium is nonlinear in the general case. The greatest wear resistance was demonstrated by the friction pair of 38KhMYuA against itself. Orig. art. has: 2 figures, 4 tables. [AP9002405]

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|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Hard Steel | | | | | | |
| Alloy | | | | | | |
| Vanadium Alloy | | | | | | |
| Cadmium Alloy | | | | | | |
| Reinforced Plastic | | | | | | |
| Polymer Physical Property | | | | | | |
| Cryogenic Effect | | | | | | |
| Friction Coefficient | | | | | | |